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PHYSIOLOGICAL EVALUATION OF THE IMPROVED ENVIRONMENTAL CLOTHING SYSTEM (IECS) THE NEW CANADIAN FORCES COLD WEATHER CLOTHING SYSTEM

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ABSTRACT

The Improved Environmental Clothing System (IECS) is a new cold weather clothing system designed to replace the current Canadian Forces in-service cold weather clothing system. The most unique feature of the system is that only the outer layer of clothing is added or removed as required to adjust the level of insulation during a change of activity level. The IECS uses Goretex® as a water-vapour-permeable wind and water barrier to partly achieve this unique functionality. The present study compared the physiological responses of human test subjects wearing the IECS or the current cold weather clothing system(s) in a laboratory setting under carefully controlled conditions of temperature (-10°C and -40°C), wind (0.4 and 20 km/h), and activity (rest or intermittent work). Measurements included physiological data (deep body temperature, skin temperatures, heart rate, sweat loss), body heat exchange, and subjective thermal comfort. The results showed numerous instances in which the IECS demonstrated superior performance over the current in-service clothing systems. It generally performed "better" than the other clothing configurations under most conditions by preventing excessive cooling during periods of inactivity and reducing overheating during work. The flexibility, simplicity, good looks, good feel, and overall comfort of the IECS show that it is well designed, and it was certainly well liked by the subjects. The most important attribute of the IECS is that it finally brings the layering principle into practicality, and it does this with no sacrifice, and possibly even some significant gains, in thermal protection against the cold.

Key words: protective clothing, cold stress, comfort, Goretex, breathable fabric

EXECUTIVE SUMMARY

A new cold weather clothing system for the Canadian Forces (CF), known as the Improved Environmental Clothing System (IECS), has been in development for a number of years. The most unique feature of the system is a novel approach to the layering principle in which the outer layer of clothing is added or removed as required to adjust the level of insulation during a change of activity level. This is in direct contrast to other concepts in which it is the underlayers which are added or removed to vary insulation. Donning/doffing only the outer layer greatly simplifies insulation adjustments and reduces the number of clothing elements comprising the system. The IECS uses Goretex® as a water-vapour-permeable wind and water barrier to help achieve this unique functionality.

The present study was undertaken to compare the physiological responses of human test subjects wearing the IECS to those when wearing the current cold weather clothing system(s) in a laboratory setting under carefully controlled conditions of temperature (-10°C and -40°C), wind (0.4 and 20 km/h), and activity (rest or intermittent work). Measurements included physiological data (deep body temperature, skin temperatures, heart rate, sweat loss), body heat exchange, and subjective thermal comfort.

The results of this study showed numerous instances in which the IECS demonstrated superior performance over the current in-service clothing systems. Some of these instances showed the IECS to be warmer than the current system, sometimes cooler, and sometimes it showed no change across test conditions. The point is that the IECS generally performed "better" than the current clothing under most circumstances by preventing excessive cooling during periods of inactivity and reducing overheating during work. The flexibility, simplicity, good looks, good feel, and overall comfort of the IECS show that it is well designed, and it was certainly well liked by the subjects. Perhaps the most important attribute of the IECS is that it finally makes the layering principle practical, and it does this with no sacrifice, and possibly even some significant gains, in thermal protection against the cold.

From a thermal physiological perspective, this clothing system is recommended for further development and implementation.

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INTRODUCTION

Military cold weather clothing must protect the wearer against the elements of wind, snow, and rain. Concomitantly, it must provide varying amounts of insulation so as to match the amount of heat loss to the environment with the level of body heat production associated with a wide range of activities. The required maximum amount of insulation is generally set by what is needed to keep a resting individual warm for several hours under the coldest expected ambient conditions. However, as environmental temperature increases, or as increased activity and work rate raise heat production within the body, the requirement for insulation decreases. If insulation is not reduced, heat production will exceed heat loss, resulting in a positive heat balance in the body and a storage of the excess thermal energy. This will lead to a rise in deep body temperature, an increase in sweat production, and the possible wetting of the clothing by sweat. Since the absorption of substantial quantities of moisture in clothing can greatly reduce its insulation value, prevention of excess sweating in the cold in the face of varying levels of activity is a major challenge facing designers of Arctic clothing systems.

One approach to meeting this requirement that has long been pursued is the "layering principle". In theory, the ideal cold weather clothing ensemble is made up of several layers of lesser insulation, each contributing to the total insulation, and layers of clothing are removed or added as needed to maintain thermal balance. In practice, success with this approach has often been difficult to achieve. First, the outer clothing layer is often the only layer that provides the essential protection against the environmental hazards, and much of the total insulation has often been associated with this layer. This effectively makes the outer layer non-optional, and its associated insulation can at times be excessive. A secondary effect of this design is that those layers that can be added or removed are beneath the outer layer, which necessitates several steps to adjust one's insulation and creates a storage problem for those inner layers which have been removed and must be kept dry. More often than not, particularly in a military setting, the logistics of adjusting insulation with such a system are simply impractical, with the result that soldiers are often wearing levels of insulation that are less than optimal. Indeed, excessive insulation has likely been the cause of much cold injury in the past.

A recent technological advance that has virtually revolutionized clothing design is the development of water-vapour-permeable water-proof materials (WVP/WPMs) which can be bonded to layers of fabric. The major benefit of these materials is that they allow water vapour to diffuse through the clothing while providing a barrier to wind and water. While several varieties of such materials exist today, the most well-known is expanded polytetrafluoroethylene (PTFE) sold under the trade name Goretex®. WVP/WPMs have found their way into a variety of clothing systems, particularly sports clothing where activity levels vary greatly and the environmental conditions range from extreme heat to extreme cold. WVP/WPMs can be used very effectively wherever there is a need in a single garment system to enhance evaporation of body sweat due to activity while keeping out external water. An excellent example of such use is the manufacture of firefighter turnout clothing [1]. While the development of WVP/WPMs is in itself important, the method of incorporation of such materials into an affective garment system design is of equal if not more importance.

WVP/WPMs have made possible the development of garment systems with unique functionalities. One of these systems is the Improved Environmental Clothing System (IECS) developed over a period of years by Defence Research Establishment Ottawa (DREO) and recently engineered by the Directorate of Clothing, General Equipment and Materials (DCGEM; now renamed Directorate of Acquisitions, Clothing, Materials, and Equipment (DACME)). The main distinguishing feature of this new system is that it comprises only three clothing layers: an inner fleece pile fabric worn next to the skin during extreme cold (literally, a warm track suit), a middle layer (combat jacket and pants) which is uninsulated but contains Goretex® for wind and water protection, and an outer insulated layer (parka and coveralls) also containing Goretex®. The IECS was designed to replace both the current wet cold and the current extreme cold clothing systems with a single system that would cover the ambient temperature range of +10 to -40°C and bring the layering principle to practical fruition in the Canadian Forces (CF).

Components and aspects of the IECS were evaluated numerous times during the various stages of its development, but it was not until 1992 that an operational and field-deployable configuration of the IECS was produced in large numbers. At that time a series of parallel field and laboratory trials were undertaken to evaluate and compare performance of the IECS with the existing CF cold weather clothing ensembles [2; 3; 4]. This report describes the results of trials of the IECS conducted under controlled environmental conditions in the climatic chambers at the Defence and Civil Institute of Environmental Medicine (DCIEM) between September 1992 and February 1993. The tests were conducted in response to a tasking from Directorate of Land Requirements (DLR) through DREO to DCIEM.

MATERIALS AND METHODS

Subjects

A total of ten volunteer subjects were recruited from the ranks of Land Forces Central Area (LFCA) at Canadian Forces Base (CFB) Toronto. All three elements of the CF (i.e., land, air, and sea) were represented in the subject sample, and none of these subjects had any prior experience with the IECS. Also participating in the trials were two subjects from DLR in Ottawa who were intimately familiar with the IECS. The ages of the subjects ranged from 23 to 38 y, with a mean age of 29 ± 5 y (mean ± S.D.). They were selected to be of medium build simply because of the limited range of clothing sizes available for the study. Eight subjects were used in each of two test series conducted at -10°C and -40°C (see below). Subjects 1–8 participated in the -10°C test, while subjects 1–4 and subjects 9–12 participated in the -40°C tests.

All subjects were screened by a physician prior to their being accepted into the tests and were declared physically fit and in good health. They were briefed on the experimental procedures and they gave their written informed consent to participate. All procedures employed in these tests were passed by the DCIEM Human Use Ethics Committee.

Clothing

In essence, two clothing systems were being compared in these tests: the current clothing and the IECS. However, each of these major categories can be subdivided into sub-categories appropriate to the environmental conditions under which testing was carried out (see below). For example, the current clothing consisted of two main configurations, current temperate (**CT**) and current cold (**CC**), while the IECS was worn either in the new temperate (**NT**) configuration or in the extreme cold configuration. Since two levels of insulation were specified and fabricated for the outer parka and coveralls of the IECS, the extreme cold configuration of the new clothing was further subdivided into light parka (**LP**) and heavy parka (**HP**). Apart from the quantity of insulation and a minor change in the fibre and weave of the outer face fabric, the **LP** and **HP** systems were functionally identical. Detailed physical characteristics of the

IECS can be found in a companion study [3]. (NOTE: In the companion study [3] the **LP** and **HP** systems are designated System A and System B, respectively.)

Two "dressing" approaches were considered for the experimental design. Option A was to present subjects with all of the clothing elements of a particular configuration (IECS or the current clothing) each day and allow them to choose the items they felt would be most suitable for the pending test. Once clothing was chosen, no changes (i.e., no additional items) would be allowed. A variation would be to allow them to take extra items of clothing with them into the chamber, but these would have to be "carried" if not worn, just as if on exercise in the field. Option B was to force all subjects to wear a given set of clothing items deemed to be most appropriate for the test conditions.

Drawbacks to Option A were abundant: most subjects had no idea at the outset of the study what the environmental test conditions would feel like, making appropriate clothing selection difficult; they certainly had no experience with the IECS, again making clothing item selection difficult; and they would gain familiarity with both as time progressed, allowing a certain bias to enter into the study. It would also be difficult to perform statistical analyses on physiological responses if clothing conditions varied widely between subjects. The main drawback to Option B was that we could be assigning inappropriate clothing configurations under the various test conditions, thereby also biasing the results either in favour of or against a particular configuration. However, this could be avoided by conducting a set of preliminary tests in which dress configurations could be fine tuned for each test condition prior to the main study. Although this would involve extra work, the benefit would be identical treatment of each subject under a given test condition and the opportunity to perform statistical analyses on the results. These were considered significant advantages, and Option B was adopted.

As already stated, each clothing configuration was modified slightly to be most suitable for each test condition. A detailed list of clothing items worn under each test condition is given in Appendix A. A simple list of clothing items comprising the main clothing configurations of each system is presented below in Table 1. Clothing items of similar function are aligned somewhat in rows.

Table 1. Partial List of Clothing Items Comprising the Various Test Ensembles

Current Clothing		IECS	
CT	**CC**	**NT**	**LP / HP**
undershorts tee-shirt	undershorts tee-shirt	under shorts tee-shirt	under shorts tee-shirt
	honeycomb top long johns		fleece top fleece bottom
combat shirt combat jacket	flannel shirt sweater, scarf	middle layer jacket	middle layer jacket
combat pants		middle layer pants	middle layer pants
	parka wind pants	outer parka†	outer parka† outer coveralls†
toque combat boots combat gloves	balaclava mukluks Arctic mittens	toque combat boots combat gloves	balaclava mukluks Arctic mittens

† these items were worn as needed

Note that the IECS does not include any new head, hand, or foot wear. Thus, the clothing items worn on these areas of the body during testing of the IECS were the same items that would have been part of the current clothing ensembles. Note also that with the IECS system the outer layer parka and coveralls were worn "as required" to adjust the level of insulation.

Experimental Design

The objective of this study was to obtain a comparison of the physiological responses to wearing the various clothing configurations under two different levels of activity and two different wind conditions, all at two different temperatures. Accordingly, a 3-factor repeated measures experimental design containing 12 cells was adopted as shown in Figure 1. Note that the same experimental design was used at both -10°C and -40°C. However, since clothing configurations and composition of the subject samples varied between these two test temperatures, each temperature series was treated (i.e., analyzed) as a completely separate experiment. (Since four subjects participated in both series, it would neither be correct to treat temperature as a "between" factor, nor would it be statistically useful to treat it as a "within" factor with an "n" of only four.) Subjects were tested in pairs at the same time of day (morning or afternoon) for four days each week for three weeks. Treatment order was counterbalanced to minimize the effects of any potential acclimation to the cold (little acclimation was expected due to the relatively short exposures and the fact that the subjects were wearing sufficient clothing to hopefully create a fairly comfortable microclimate within the clothing).

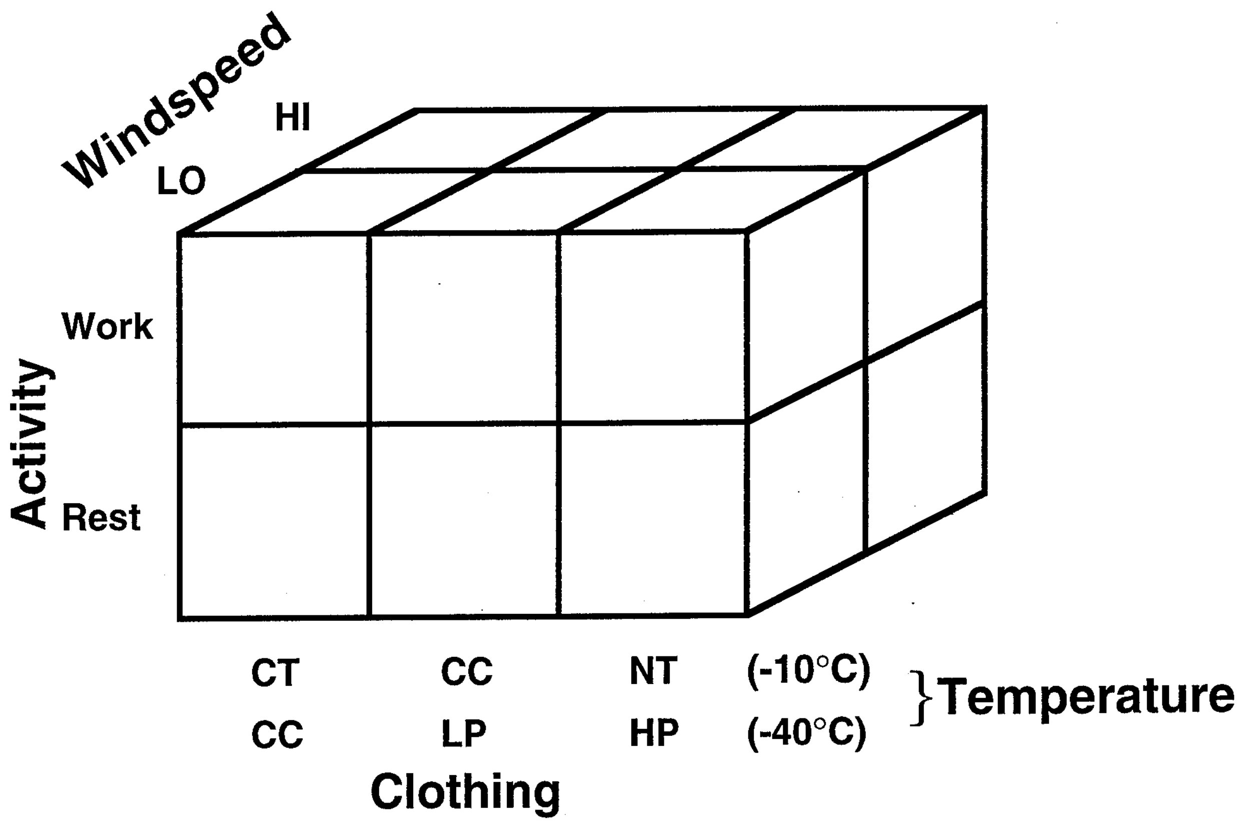

Figure 1: Graphic representation of the 3-factor repeated measures design. Each subject was exposed once to each test condition, and the -10°C and -40°C tests (of 12 cells each, as above) were treated as completely separate studies.

The main factor **Activity** consisted of two activity schedules. During **Rest**, subjects entered the environmental chamber and simply sat on a wood bench covered in a thick wool blanket with their backs to the wind. They were allowed a "stretch break" for two minutes every 20 minutes to exercise stiffening joints (particularly the knees). During **Work**, subjects entered the environmental chamber and spent 40 minutes of each hour working and 20 minutes resting. The work involved walking on a level treadmill at 4.5 km/h or carrying 105 mm drill rounds a distance of 2 m at a rate of 6 rounds moved per minute. The drill rounds were placed on a rack at each end of a 2 m platform and the heights of the rack (30, 60 and 90 cm) were set to be representative of an actual weapons loading task. The three rounds were moved from one rack to the other at a cadence set by flashing lights connected to a timer. After 20 minutes, subjects switched to the other work task. This cycle was repeated twice, and the final 30 minutes comprised only 15 minutes on each task. Note that half of the subjects began work on the treadmill while the other half began on the loading task. The main factor **Wind** included a **LO** wind speed (0.4 km/h, the minimum wind speed in the cold chamber) and a **HI** wind speed (20 km/h) condition. Subjects had their backs to the wind while sitting or walking, but had to turn face into the wind while loading/unloading drill rounds from one of the racks.

The main factor **Clothing** has already been addressed briefly above, and detailed descriptions of the items worn for each test condition are given in Appendix A. However, the rationale for the clothing selections and the two environmental temperatures should be clarified.

The "design philosophy" behind the IECS was that this single 3-layer system should replace both the current wet cold and the current extreme cold clothing systems, thereby providing proper protection under all environmental conditions ranging from +10°C (including wet cold conditions) down to the -40°C dry cold of the Arctic. Hence, the tests at -40°C were designed to assess the adequacy of the IECS insulations (**LP** vs **HP**) in extreme cold and to compare them to the current cold (**CC**) clothing configuration. Of course, not all components of the IECS would be carried at all times (clearly, one would not carry insulated parkas when temperatures are +10°C); rather, a judicious selection of items would be chosen based on the environmental conditions and operational requirements of the day. However, the implication is that one might not have the appropriate clothing items if circumstances change drastically during the day, particularly if ambient temperatures transgress the transition zone where a major change in clothing configuration would be desirable.

The design transition temperature for the IECS where one would wear the inner layer fleece is about -10°C. This is also about the temperature at which one would consider wearing the insulated parka of the current clothing system. Thus, -10°C was selected as an ambient condition at which there might be a "penalty" for having chosen the clothing incorrectly. Accordingly, clothing configuration **CT** during the -10°C tests represented a situation in which inadequate insulation had been selected, as if warmer conditions had been expected but the temperature suddenly dropped to -10°C. Similarly, configuration **CC** represented a situation in which too much insulation had been selected, as if the day had begun quite cold and then warmed up unexpectedly to -10°C. With the IECS, configuration **NT** permitted assessment of whether the fleece could be omitted down to -10°C (i.e., is the middle layer sufficient insulation during condition **Work**, and can the outer parka provide sufficient additional insulation during condition **Rest** even in high wind?).

All tests were designed to be of 150 min duration. Subjects were, of course, free to terminate any test for any reason whatsoever. Other termination criteria included rectal temperatures rising above 39°C or dropping below 35°C, rectal temperatures changing by more than ± 2°C from the temperature at the start of the test, any skin temperature dropping below 3°C, or heart rate exceeding 80% of the age-predicted maximum heart rate (220 - age) for three consecutive minutes. The investigators and/or the attending physician could also terminate any test for reasons of safety.

Measurements

Rectal temperature (T_{re}) was measured with a thermistor (Pharmaseal 400 Series Rectal/Esophageal) inserted 15 cm beyond the anal sphincter. Skin temperatures and local heat fluxes at 12 standard sites (see Appendix A) were measured with heat flux transducers (Concept Engineering, Model FR-025-TH44018-F12) attached to the skin with Transpore (3M Corporation) surgical tape. Mean skin temperature (MST) and mean heat flux (MHF) were calculated using the area-weighted average of the 12 sites (see Appendix A). Additional thermistors (YSI 44004) were taped to the fingers, toes, and rear thighs for safety to prevent local frostbite. Heart rate (HR) was monitored using a single lead ECG connected through a Cardiosuny Model 501D ECG monitor to a Quinton Model 611 Cardiotach which provided an analog output voltage proportional to heart rate. All these parameters were scanned continuously with a Hewlett-Packard data acquisition system (HP 3497 Data Acquisition System, HP 9836 Desktop Computer). One-minute averages of the parameters were displayed on the screen, printed, and saved on disk for later analyses.

Subjects were weighed nude before and after each test, and the weight differences were used as an indication of fluid loss (FLOSS) during the test. Rectal temperatures were also recorded by hand before dressing and after undressing for each test. A Sport

Tester PE3000 heart rate monitor was used as a backup system for HR. These values were also recorded by hand every 20 minutes for later statistical analyses.

Throughout the tests, subjects were asked to provide subjective ratings of thermal comfort using the 13-point McGinnis scale [5] (see Appendix A). They were asked to provide separate ratings for whole body, head, hands, and feet (-10°C series) and additionally arms and legs (-40°C series). These data were also recorded by hand every 20 minutes.

Data Analyses

All initial and final time point temperature data collected by the data acquisition system were transferred to a Macintosh computer for processing and analyses. Hand-recorded data were also entered into a spreadsheet on the Macintosh system. Heart rates, comfort scores, changes in body weights, initial and final body temperatures, as well as changes in body temperatures from start to finish of the tests were compared among the various clothing ensembles across the various test conditions.

Analyses were performed with the SuperAnova statistics package (Abacus Concepts) using a repeated measures analysis of variance (ANOVA repeated, 3 within factors). Specific comparisons between clothing ensembles were done using linear means comparison contrasts. All reported statistical probabilities are based on the Greenhouse-Geiser epsilon correction for degrees of freedom as implemented in this statistics package. Results were considered significant if $p<0.05$, and Appendix B contains a summary table of all ANOVA test results. Note that in this report attention is focused on the main effect of clothing and on interaction effects in which clothing is a factor (i.e., the effects of wind and activity, either singly or in combination, on the physiological variables are not considered extensively).

For the -10°C series of tests, all subjects completed 150 min of exposure under all conditions. The final time point data are, therefore, directly comparable and are probably good indicators of the performance of the clothing systems under the various test conditions. Since temperature responses in the body are generally slow, the final values represent a somewhat integrated response over the 150 min.

Since not all subjects were able to complete the -40°C tests, statistical analyses and interpretation of the results for these tests were more complicated. In particular, "final" data from this series of tests represent physiological responses after various times of exposure; hence, they may not be directly comparable. To illustrate, if one subject's exposure were terminated relatively early (perhaps because of extreme discomfort of the hands or feet), the final deep body temperature may be considerably higher than that observed in another subject after a relatively long exposure under the same test condition in which whole body cooling was more profound. This could potentially increase the variance of the data for a particular test condition, thereby masking differences in the clothing ensembles. The corollary is, of course, that if significant differences for a variable are found, then they are genuinely significant.

To further complicate matters, the subjective comfort and heart rate data which were collected manually at 20-min intervals could not be analyzed statistically with time as a factor beyond 60 min because of the severe decrease in the number of subjects. For example, the number of subjects included in the repeated measures data analyses dropped from n=7 to n=3 when the 80-min data were included. The statistical analyses of the comfort and heart rate data at -40°C thus represent responses during the first hour only.

Because of the large volume of temperature and heat flux data collected with the data acquisition system, these data were not analyzed statistically over time other than to use the initial and final values as noted above. However, the responses of these variables over time provided valuable insight into differences in the clothing systems, and some of these data are presented in this report. Note that for the -40°C tests, the data plots represent information from progressively fewer subjects as time progresses. These later data may, in fact, give false impressions of the overall performance of the clothing because they may be data from the "most tolerant" subjects. Averaged data are presented as the mean ± standard error of the mean (SEM) unless stated otherwise.

RESULTS and DISCUSSION

The results of this study are reported separately for the two ambient temperature conditions employed.

A) -10°C Tests

Rectal Temperature (T_{re})
Initial values of rectal temperature (T_{re-i}) did not differ significantly between test conditions. While this is a desired and expected result, it is worth verifying to ensure that there was no bias in terms of elevated or depressed deep body temperature (mild hyperthermia or hypothermia) at the start of any test condition. The overall grand mean T_{re-i} was 37.31±0.04°C, which is quite normal.

The T_{re} responses over time were quite dependent upon the test conditions. Mean values over eight subjects for the three clothing ensembles and two activity levels during the **LO** wind condition are shown in Figure 2. The main feature is that T_{re} was elevated during **Work** (the bold type refers to the entire treatment, not the individual work periods) compared with **Rest** irrespective of the clothing worn, and very definite increases in T_{re} (about 0.5°C) were observed every time subjects walked on the treadmill or transferred drill rounds. During the resting phase of the **Work** protocol, T_{re} dropped by 0.2–0.3°C, only to climb again with commencement of the next activity session.

The second feature to note in Figure 2 is that the **CT** clothing configuration as worn in this study indicated the smallest overall increase in T_{re} during condition **Work**, with the major deviation in response from the other clothing ensembles beginning after about 60 min. This could be beneficial in that it may reduce the "thermal stress" of working in clothing that has excessive insulation. Clearly, changes in some of the clothing elements for ensembles **CC** and **NT** may have been able to lessen the corresponding T_{re} increases somewhat; thus, it is difficult to judge from these data alone which clothing ensemble was, in fact, better. Perhaps the most important observation in this data is that the **NT** clothing ensemble gave a response that was intermediate between **CC** (which may have been too insulative) and **CT** (which may have provided insufficient insulation) during the **Work** protocol and **LO** wind condition. During **Rest**, ensemble **NT** appeared to maintain T_{re} better in the long term than the other two configurations of the current clothing system.

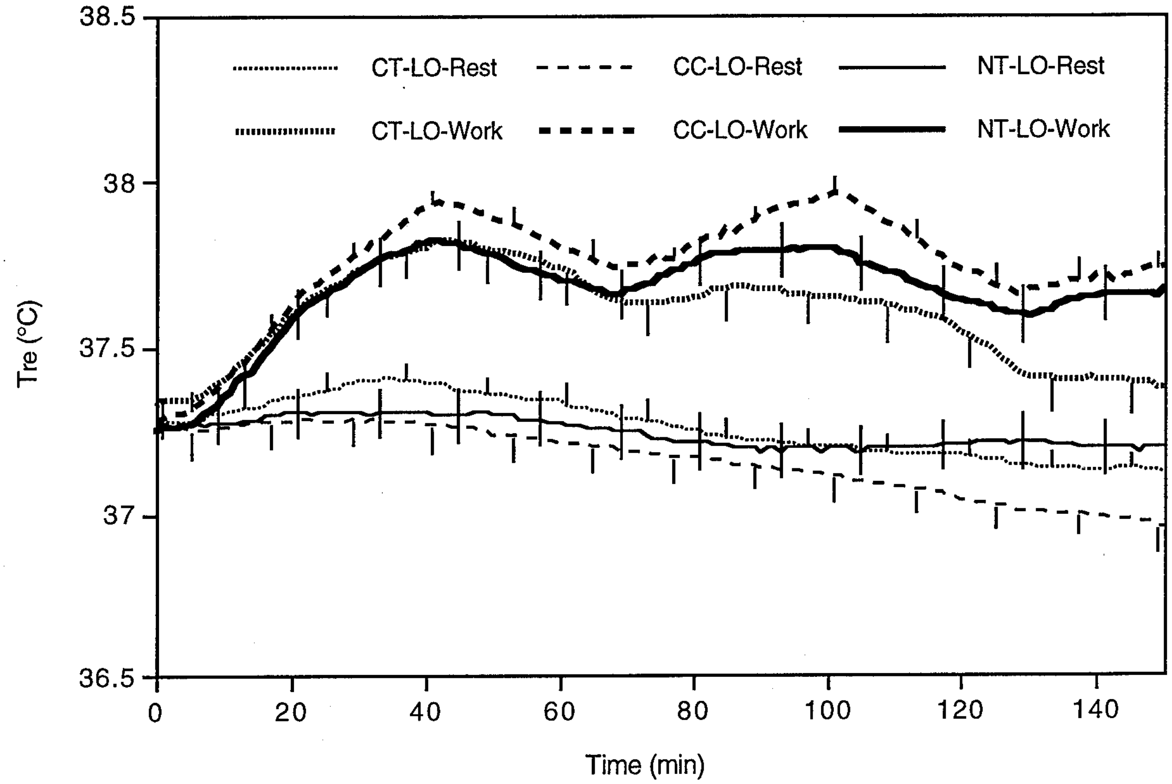

Figure 2. Mean T_{re} vs time for 3 clothing ensembles and 2 activity protocols during the **LO** wind condition at -10°C.

Although not shown, the data for the **HI** wind condition were qualitatively similar, the major difference being that T_{re} values at the end of the exposure were about 0.2°C lower with the **CC** clothing ensemble, but only about 0.1°C lower with the **CT** and **NT** ensembles. Overall, comparison of the **HI** and **LO** conditions indicated that the least difference between wind conditions occurred with ensemble **NT**, suggesting that the new clothing with its Goretex® membrane is very effective at stopping wind. As in the **LO** condition, ensemble **NT** maintained T_{re} better than either of the current clothing ensembles in **HI** wind, undoubtedly due to the warmth and wind protection of the outer layer.

Although $T_{re\text{-}i}$ did not differ significantly between conditions, there were small variations from day to day between and within subjects. Since the differences between clothing ensembles discussed above were quite small, a substantial portion of these differences could be due to the minor variations in T_{re-i}. Thus, a better comparison of the clothing can be obtained by examining changes in T_{re} (i.e., ΔT_{re}). The time course of the mean ΔT_{re} responses averaged over the eight subjects for the three clothing ensembles and two activity levels during the **HI** wind condition are shown in Figure 3. Ensemble **CT** indicated the greatest degree of cooling over time, while ensemble **NT** indicated a marginally warmer T_{re} than ensemble **CC** by the end of the exposure. The data indicate that ensemble **CT** was likely inadequate (a negative ΔT_{re} at 150 min) while ensembles **CC** and **NT** were essentially equivalent.

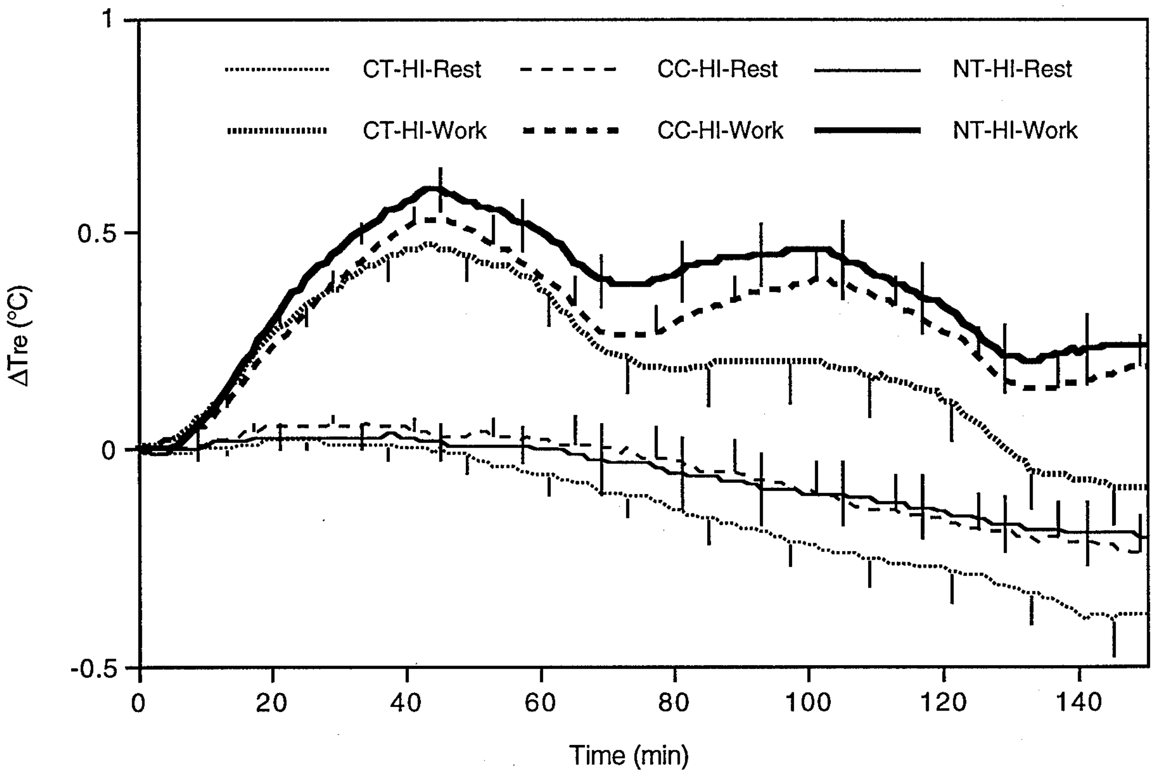

Figure 3. Mean ΔT_{re} vs time for 3 clothing ensembles and 2 activity protocols during the **HI** wind condition at -10°C.

Analysis of variance (ANOVA) performed on final rectal temperature (T_{re-f}) data after 150 min in the chamber indicated statistically significant main effects of clothing ($p<0.01$), wind ($p<0.05$) and activity ($p<0.001$). There was also a highly significant interaction between clothing and activity ($p<0.01$), with T_{re-f} in ensemble **CC** being lowest during **Rest** (36.97±0.06°C), but highest during **Work** (37.65±0.05°C).

ANOVA performed on ΔT_{re} at 150 min indicated a significant ($p<0.05$) 3-way interaction between clothing, wind speed and activity, and a summary plot for these data is shown in Figure 4. The main feature of interest is that clothing ensemble **NT** performed similarly to ensemble **CC** except during **Rest** with **LO** wind, where ensemble **NT** maintained T_{re} better than the other two clothing ensembles. Ensemble **CT** clearly showed smaller increases and larger decreases in ΔT_{re}.

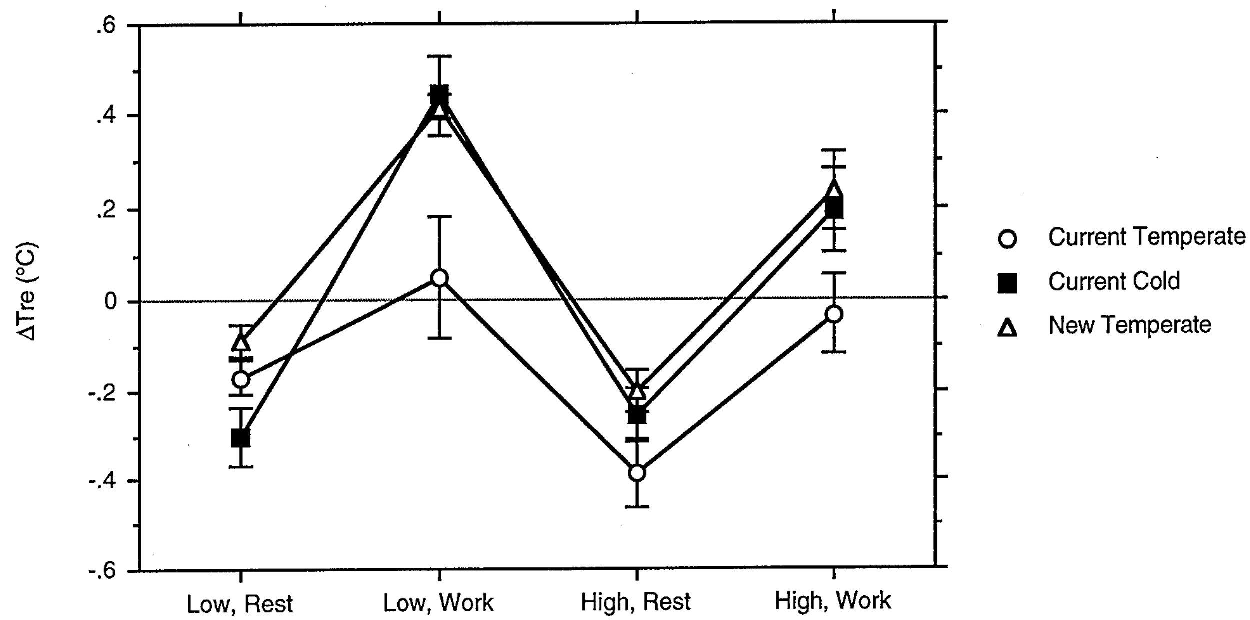

Figure 4. Mean±SEM final ΔT_{re} at 150 min for clothing ensembles **CT**, **CC**, and **NT** during activity protocols **Work** and **Rest** with **HI** and **LO** wind conditions.

In summary, from examination of the rectal temperature data over time, clothing ensemble **NT** as configured in this study provided as much or even better protection than either of the clothing ensembles based on the current clothing. Given that the IECS is a much simpler clothing system with fewer elements, this is a very positive result.

Mean Skin Temperature (MST)

Initial mean skin temperature (MST_{-i}) differed significantly between tests as a function of both clothing ($p<0.05$) and wind condition ($p<0.01$). MST_{-i} was 32.3±0.1°C with ensemble **CT** and 32.7±0.1°C for ensembles **CC** and **NT** when averaged over wind and activity, and was 32.5±0.1°C for **LO** wind vs 32.7±0.1°C for **HI** wind when averaged over clothing and activity. These results are not surprising in that there were clear differences in the amounts of insulation in the various ensembles worn for each specific condition, especially between the two wind conditions. One would expect skin temperature to be heavily influenced by this insulation during dressing prior to entering the chamber. However, no differences would be expected as a function of activity because virtually the same clothing was put on for both conditions. Despite the statistically significant differences, the actual differences were small and were of little consequence physiologically given the degree of MST cooling observed in some conditions. A normal MST for individuals at rest under room temperature conditions is about 33°C.

As for the evolution of MST over time, the results followed a rather expected pattern. During **Rest**, skin temperature tended to decrease along a smooth exponential-like curve, reaching lower values with **HI** wind compared with **LO** wind. Also as expected, skin temperatures decreased most with ensemble **CT**. During **Work**, a similar overall cooling trend for MST was observed, but with undulations superimposed. These undulations followed the work/rest intervals of the protocol and were somewhat more "pronounced" for the **HI** wind condition in which parkas were opened and closed (ensemble **CC**), or donned and doffed (ensemble **NT**). Keeping the **CC** parka on but open definitely kept skin temperatures warmer than donning and doffing the **NT** parka despite the noticeable rise in skin temperature after donning. Perhaps the **NT** parka should also have simply been opened and closed during this condition for a fairer comparison, but the objective was to see if the middle layer by itself would provide adequate protection during work. The mean MST vs time data averaged over the eight subjects for the three clothing ensembles during **Work** and **HI** wind are shown in Figure 5.

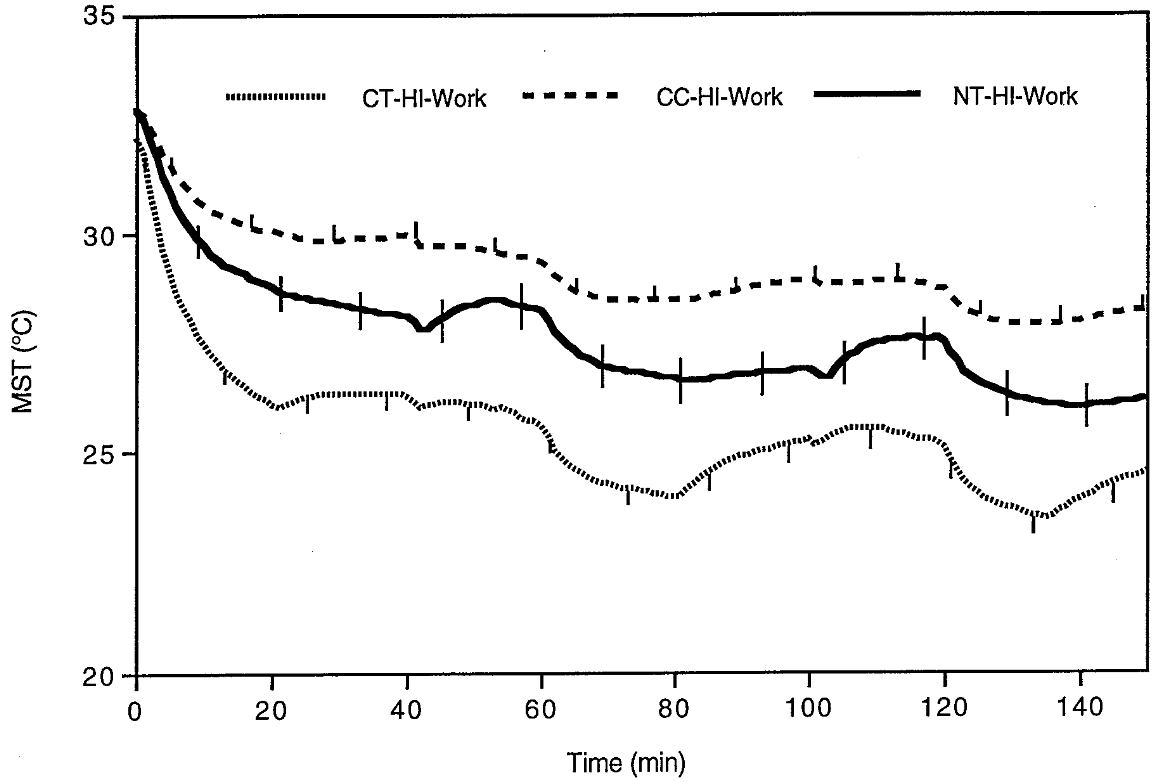

Figure 5. Mean MST vs time for 3 clothing ensembles during **Work** and **HI** wind.

ANOVA of the final mean skin temperature (MST_{-f}) data indicated significant main effects of clothing ($p<0.001$) and wind ($p<0.001$), as well as significant 2-way clothing by wind ($p<0.001$) and clothing by activity ($p<0.01$) interactions. The MST_{-f} clothing by activity interaction plot shown in Figure 6 is particularly interesting. It shows that ensemble **CT** is quite inferior to the others in being able to maintain skin temperatures at comfortable levels, especially during the **Work** condition. It also shows that whereas there is no difference between ensembles **CC** and **NT** during **Rest**, there is a clear separation of these systems during **Work**. As discussed above, the rather high value of MST_{-f} with ensemble **CC** is likely a direct result of the insulation of the ensemble because of the requirement to always have the outer shell (an integral part of the parka) on the body. Granted, the liner can be removed from the parka to reduce the total insulation, but then it must be stowed somewhere where it is not exposed to the elements. The advantage of ensemble **NT** is that wearing the outer parka during work is optional, and it provides a simple way of adjusting the insulation of the clothing to meet the changing thermoregulatory requirements of working in the cold. (Note that storage of the IECS outer parka is not a problem because it folds up into its integral pocket and turns into a bag with shoulder straps.) As to which response is more desirable, the FLOSS data indicated 58% more sweat loss with ensemble **CC** compared to ensemble **NT** (see below).

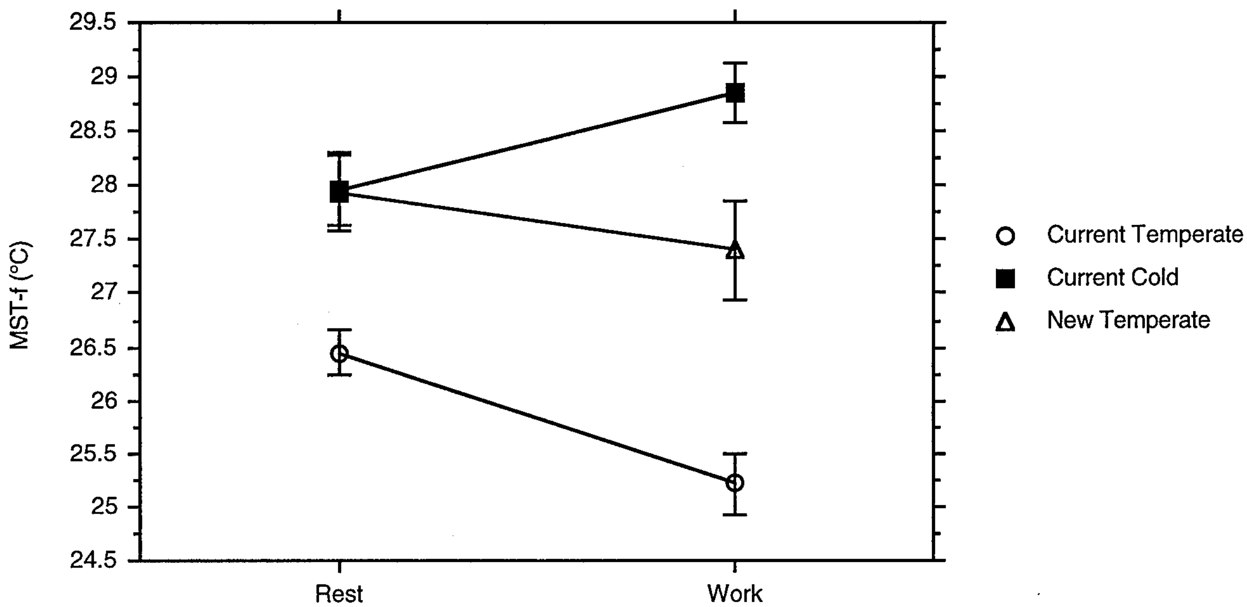

Figure 6. Mean±SEM MST-f at 150 min for clothing ensembles **CT**, **CC**, and **NT** during activity protocols **Work** and **Rest** averaged over **HI** and **LO** wind conditions.

Mean Heat Flux (MHF)

Heat flux transducers provided a direct measure of the radiative, conductive and convective heat losses from the skin to the clothing and ultimately to the environment. The sensors are quite sensitive and have a very fast response time, making individual site recordings over time look rather "noisy". However, extensive time-averaging and body-surface-area weighting of the 12 measurement sites to obtain mean heat flux (MHF) for the whole body provide quite usable data. MHF data were not analyzed statistically, but rather by comparison of the plots over time.

As might be expected from the MST data above, heat fluxes were greater and more variable during **Work** than during **Rest**, they were greater during **HI** wind than during **LO**, and they were greater with ensemble **CT** than with either **CC** or **NT**. Also as before, the **HI** and **LO** conditions were qualitatively similar, so only the **HI** wind condition data are presented graphically; they are shown in Figure 7 averaged over the eight test subjects.

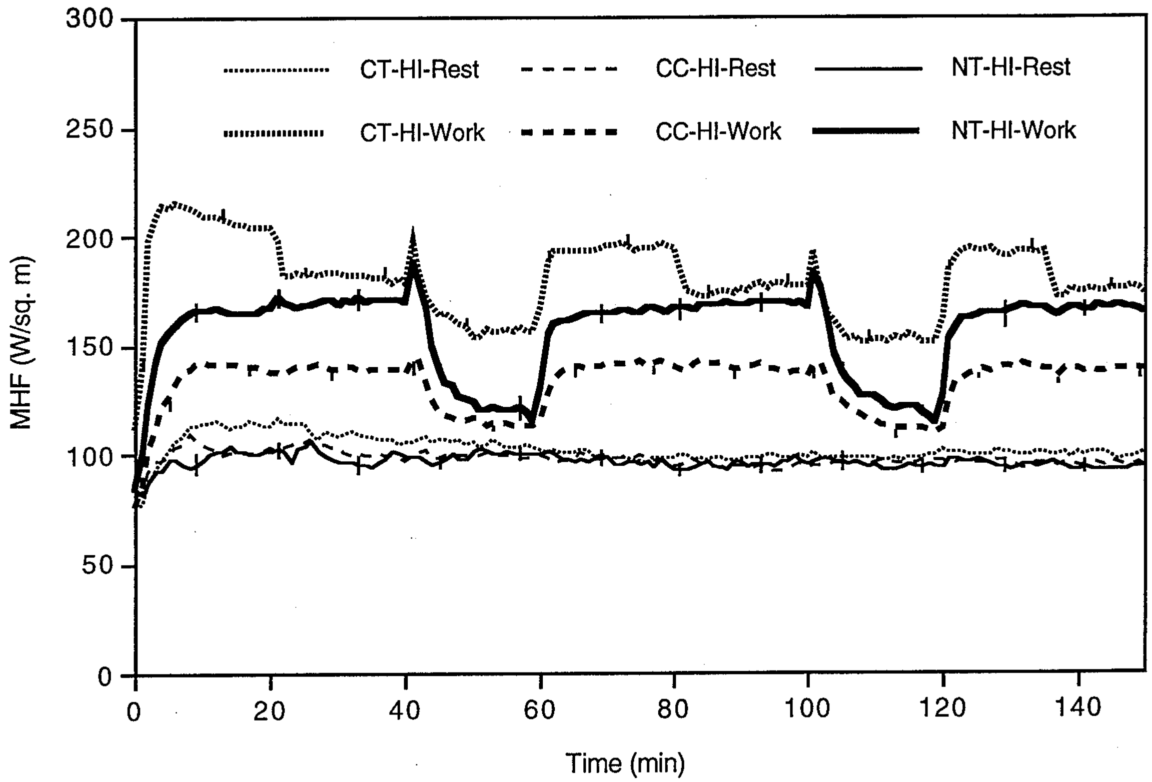

Figure 7. Mean MHF vs time for 3 clothing ensembles and 2 activity protocols during the **HI** wind condition at -10°C.

Perhaps the most striking observation in Figure 7 is the remarkable steadiness over time and similarity across clothing ensembles of the MHF during **Rest**. Time to reach steady state was considerably longer with ensemble **CT** (about 60 min) than for ensembles **CC** and **NT** (about 15 min), and the heat loss was about 10% greater with **CT** during this time. MHF did eventually level off at about 95 W•m^{-2}, which is nearly double the normal resting heat loss of a person at rest under normal room conditions.

During condition **Work**, heat fluxes were considerably higher during the work phases (0–40 min, 60–100 min, and 120–50 min) than they were during the resting phases (40–60 min and 100–120 min). During the work phases, MHF was about 20% greater with ensemble **NT** than with ensemble **CC**, again due to the fact that with **NT** the parka was doffed during work while it was only opened with ensemble **CC**. However, during the resting phases when parkas were worn and closed, heat fluxes were much more similar.

The large shifts in MHF at 20, 80, and 135 min for ensemble **CT** during **Work** are elusive. They are certainly not related to clothing adjustments because no consistent major changes were made at these times. Although the two work tasks of treadmill walking and artillery shell stacking were different and handwear was altered from mitts during walking to gloves during shell handling, the activity sequences were counterbalanced across subjects. Thus, one would have expected only minor discontinuities at activity changeover. The decrease in MHF during the resting phase is expected as it reflects reduced heat production in the body. Perhaps a component of the larger MHF after any rest period reflects a major change in body heat production and hence heat loss or perhaps a redistribution of blood flow, but why it should remain steady for 20 min and then drop is puzzling. Note that this phenomenon was not observed during the **LO** wind condition.

Body Weight Changes (FLOSS)

Fluid loss (FLOSS) data showed statistically significant differences for the main effects of clothing ($p<0.01$) and activity ($p<0.01$), as well as a significant interaction between clothing and activity ($p<0.01$). The latter finding is presented in Figure 8.

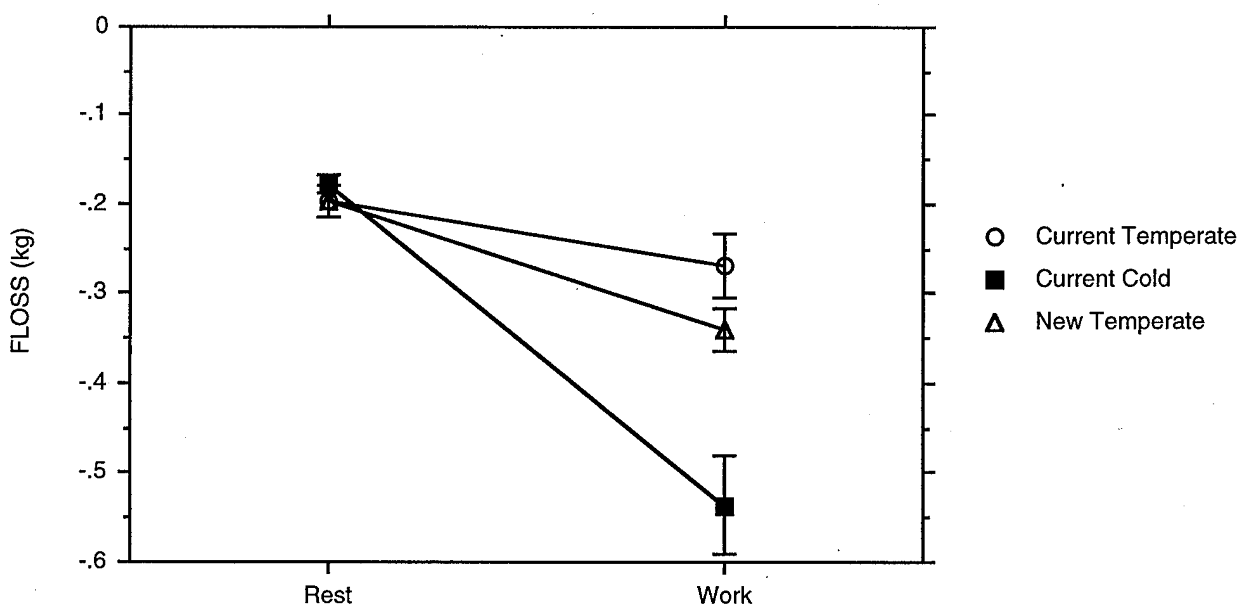

Figure 8. Fluid loss as a function of clothing and activity at -10°C. More negative values on the ordinate indicate greater fluid loss.

During condition **Rest**, fluid losses were virtually identical in all three clothing ensembles, amounting to 0.191±0.009 kg over the 150 min duration of the tests. Fluid losses increased to 0.269±0.036 and 0.339±0.024 kg for ensembles **CT** and **NT**, respectively, during **Work** while FLOSS was 0.537±0.055 kg with ensemble **CC**. Clearly, although heat losses were lower and skin temperatures were higher with ensemble **CC**, the sweat loss was considerably greater in this ensemble (58% higher than for **NT**), and that is highly undesirable in Arctic clothing. This finding indicates a significant performance advantage of the IECS over the current clothing in that the insulation level can easily be adjusted to prevent overheating and sweat-soaking of the insulation.

Heart Rate (HR)

It is not surprising that activity and time were the significant main effects influencing HR, and that there was a statistically significant interaction ($p<0.001$) between them. The interaction plot is shown in Figure 9. HR remained at normal resting levels during condition **Rest** following a small transient elevation at 0 min related to the dressing and chamber entry activities. By comparison, HR was in the 95–105 bpm range during the work phase of condition **Work**, but dropped to almost resting values during the rest interval. Clothing, wind speed and activity also presented a statistically significant interaction although the differences (range of <6 bpm) were too small to be of physiological significance for heart rates that were always below 110 bpm. However, looking carefully at the data, it was clear that during the work phases of condition **Work** HR with ensemble **NT** was always between the values obtained with ensembles **CT** and **CC**. These HR data can be interpreted as a crude indication of the work load associated with carrying the weight of the clothing and/or the restricted range of motion when working in a parka (recall that subjects always wore the parka in condition **CC**) and the results are again positive in favour of the IECS.

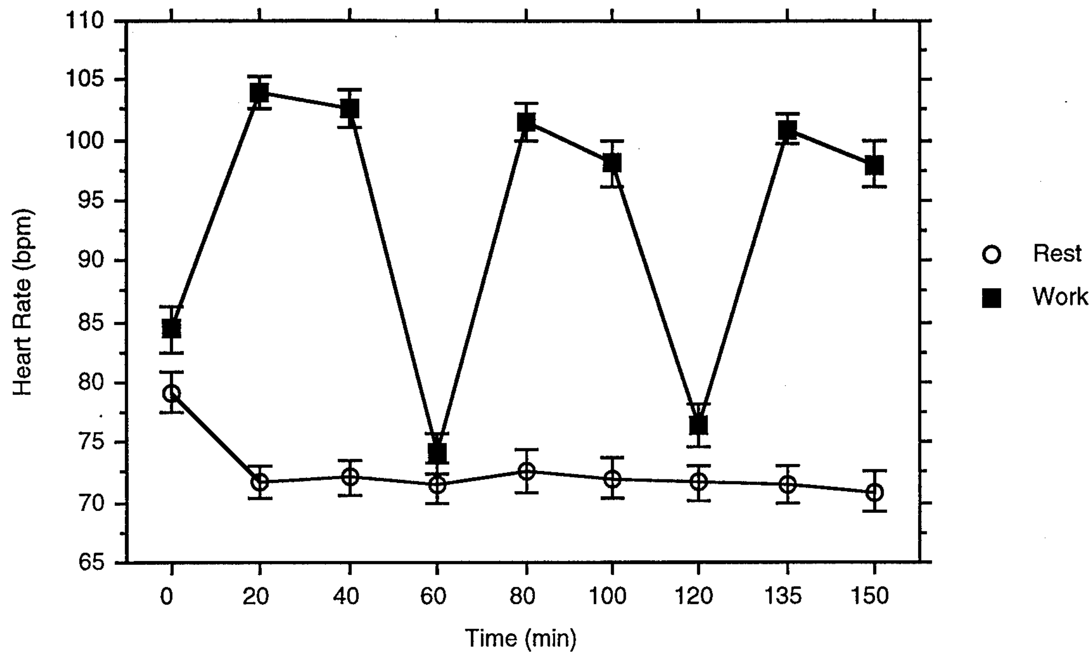

Figure 9. Heart rate vs. time for conditions **Work** and **Rest** at -10°C. Clothing and wind speed had no effect and the results are averaged over both of these factors.

Subjective Thermal Comfort

All results presented to this point can be considered objective measures of the clothing system performance. However, the ultimate purpose is to develop a clothing system that is acceptable to the user, and to this end subjective assessments are important. In the -10°C test, subjective thermal comfort ratings were obtained for the head, hands, feet, and whole body even though the IECS does not include new clothing elements for the extremities. These body parts were included to see how the clothing worn on the rest of the body would affect comfort of the head, hands and feet.

In general, thermal comfort declined over time, which is not surprising. Overall mean scores at 150 min were approximately 6.8 for the head, 6.0 for the whole body, 5.4 for the hands, and 5.3 for the feet. The influence of activity could clearly be seen in that during **Rest** the declines were quite smooth whereas during **Work** the ratings undulated in response to the cyclic activity. In the majority of cases when data were separated according to clothing, the **NT** ensemble scores were between those of ensembles **CC** and **CT**.

Because subjective thermal comfort ratings depended so much on activity with time, average values over the duration of the exposure were deemed to be suitable measures of the overall comfort levels for each test. This is, in fact, the way ANOVA methods present the results that do not involve time as a factor. Thus, average values of thermal comfort presented below will often be higher than the lowest comfort rating given since they include comfort ratings taken early in the exposure.

Statistically, clothing had a significant main effect on all four body site comfort scores. There were also statistically significant 2-way interactions of clothing by wind (on the head, hands and feet) and clothing by activity (on the head, hands, feet, whole body), as well as a significant 3-way interaction of clothing by wind by activity (on the head and feet). This latter interaction for head comfort is plotted in Figure 10 and shows an interesting pattern. Most noteworthy is that ensemble **NT** elicited very similar comfort ratings regardless of the wind and activity conditions, demonstrating that the IECS is quite adaptable to a range of operational conditions. By comparison, ensemble **CC** was likely too warm during **LO** wind and **Work**, while ensemble **CT** did not provide sufficient protection during **HI** wind and **Work**. Means comparison contrast analyses indicated that these two clothing ensembles differed significantly ($p<0.01$) from ensemble **NT** under these two conditions.

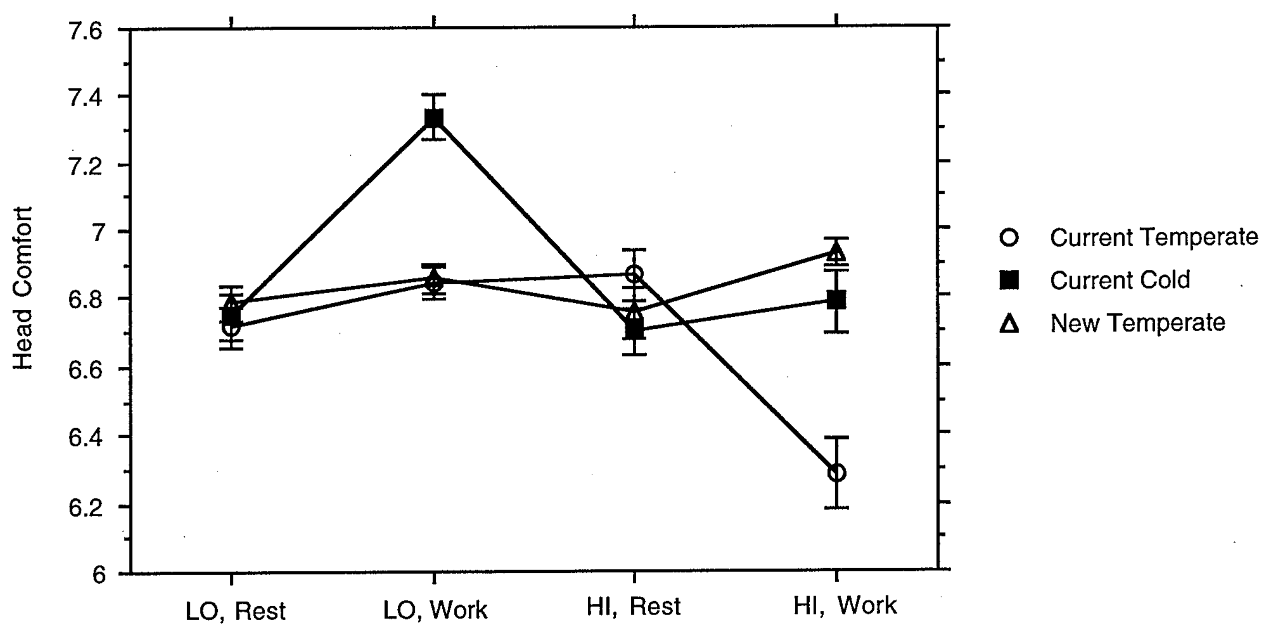

Figure 10. Head comfort with the three clothing ensembles under the various test combinations of wind (**LO**, **HI**) and activity (**Work**, **Rest**) averaged over time.

Figure 11 shows the clothing by activity interaction for whole body comfort and is further evidence of the superiority of the IECS in maintaining comfort across varying conditions. Although the rating was lower than for the head in Figure 10, it remained steady between **Work** and **Rest** (averaged here over both wind conditions). The comfort ratings with ensemble **CC** during **Rest** were comparable to those of ensemble **NT** but showed perhaps too much warmth during **Work**. This is consistent with the MST and FLOSS data presented previously. Ensemble **CT** provided lower comfort scores that even decreased between conditions **Rest** and **Work**. Contrast comparisons at the clothing by wind speed by activity interaction level indicated that ensemble **NT** differed significantly from ensemble **CC** during both wind conditions for the **Work** protocol, and from ensemble **CT** for all conditions but **HI** wind with **Rest**.

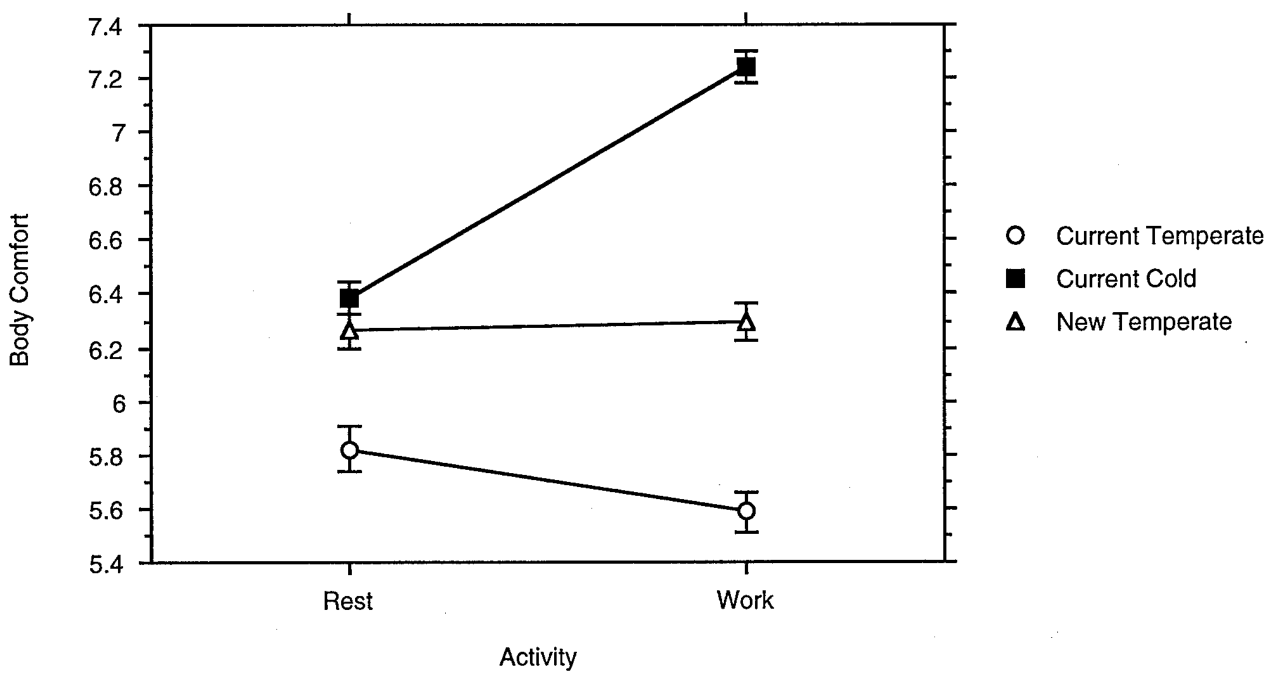

Figure 11. Whole body comfort with the three clothing ensembles under the two activity conditions (averaged over wind and time).

As a general summary of the thermal comfort results, subjects preferred the IECS over the current clothing system. It allowed simple adjustments to the insulation levels to accommodate various activity levels, and its insensitivity to wind, probably due to the Goretex® membrane, demonstrates a superior garment system.

B) -40°C Tests

Before discussing any specific results of the -40°C tests, a few points about the clothing ensembles used in this series should be pointed out. During the **Work** protocol and **LO** wind condition, the outer parka of the IECS was never worn. It was, however, put on during the rest phase of the **Work** protocol under the **HI** wind condition, and it was also worn during the **Rest** protocol under both wind conditions. The coveralls of the IECS were only worn during the **Rest** protocol with **HI** wind. These procedures were instituted to see if removal of the IECS parka was beneficial in preventing sweat buildup in the clothing, and at the same time to see if the inner and middle layers would provide adequate insulation during physical activity. Should these procedures indicate insufficient protection, the outer layer could, of course, be added. By comparison, the parka of the **CC** ensemble was always worn but was opened and closed between the work and rest phases of the **Work** protocol to permit some ventilation. Thus, there was less flexibility in dressing in the **CC** ensemble. As in the -10°C tests, slight modifications to the ensembles were made for specific conditions, as detailed in Appendix A.

Tolerance Times

A major difference between the -10°C and -40°C tests was that subjects were often unable to tolerate the extreme cold conditions for the planned 150 min duration. Of the 96 tests conducted, 56 tests or 58.33% were terminated prematurely, with about 70% of these at the request of the subject. The shortest tolerance time was 14 min and occurred during the **Work** protocol **HI** wind condition while wearing ensemble **CC**. While this short duration was clearly an anomaly, the next shortest time was 56 min, and seven tests (≈ 7%) lasted less than 60 min.

The mean tolerance times over eight subjects for the 12 test conditions are shown in Figure 12. The number of subjects who completed the full 150 min duration are indicated above each bar. Interestingly, clothing as a main factor did not have a statistically significant effect on tolerance time, suggesting that all three clothing ensembles may have provided similar levels of protection. However, inspection of the means for each clothing type under each test condition indicated that ensemble **CC** resulted in slightly shorter tolerance times during **Rest**, particularly with **HI** wind. During **Work**, ensemble **CC** resulted in tolerance times that were comparable to those with the IECS. Omitting the subject with the 14 min tolerance time from the **HI** wind **Work** condition raised the mean tolerance with ensemble **CC** to 121 minutes, only slightly exceeding the values obtained with the IECS. Considering that the IECS was frequently worn with the parka off, this is an indication that the IECS ensemble can provide more warmth overall than the current clothing. It is re-emphasized, however, that these findings were not statistically significant. The results have been presented only because the objectives of the study were to compare the various clothing ensembles and tolerance time to cold is an obvious variable to consider. Further analyses using means comparison contrasts indicated no differences between the light (**LP**) and heavy parka (**HP**) ensembles, and no differences between the current clothing and the two IECS variations, with regard to tolerance times.

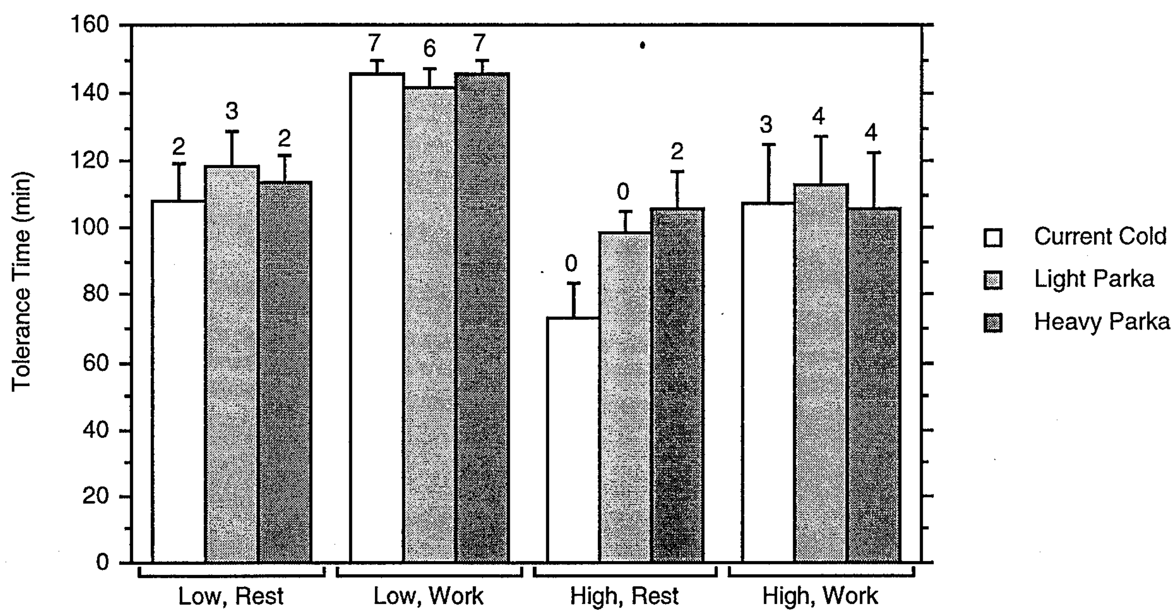

Figure 12. Mean tolerance time for the 12 test conditions. Vertical bars depict the SEM. The abscissa labels represent wind speed and activity protocol combinations. The numbers above each bar indicate the number of subjects who tolerated the full 150 min duration.

Not unexpectedly, wind speed and activity did have statistically significant effects on tolerance times ($p<0.01$ for both). During the **Work** protocol, more internal body heat would have been produced compared to during the **Rest** protocol, and mean tolerance times were 127±5 and 103±4 min, respectively (i.e., 23% longer during **Work**).

Tolerance times were 27% longer in the **LO** wind condition (129±4 min) than in the **HI** wind condition (101±5 min), undoubtedly related to the greater convective heat removal during the **HI** wind condition.

Two notes regarding the results and analyses that follow: 1) it is re-emphasized that, due to the variations in tolerance times, "final" data comparisons involve values from widely differing exposure times; and 2) data from later times predominantly comprise the responses of the more "cold tolerant" subjects.

Rectal Temperature (T_{re})

As in the -10°C test, T_{re-i} was checked for uniformity across trials and no significant differences were found. The overall grand mean was 37.28±0.05°C and was again quite normal. Thus, no tests were biased by an unfair initial deep body temperature.

Activity was the only statistically significant factor affecting T_{re-f} ($p<0.001$). During the **Rest** protocol, the mean T_{re-f} averaged over all subjects, wind conditions, and clothing ensembles was 36.99±0.07°C while during **Work** it was 37.36±0.07°C. This result is even clearer if one uses the parameter ΔT_{re}. During **Rest**, ΔT_{re} was -0.29±0.05°C while during **Work** the change was positive and was 0.10±0.05°C. The influence of internal heat production during activity is quite evident in these data. Note, however, that there were no significant interactions between any of the main factors for T_{re-f}.

A plot of ΔT_{re} against time during the **LO** wind condition is shown in Figure 13. During the **Rest** protocol of the **LO** wind condition deep body temperature remained steady for about 40 min, followed by a rather steady decrease at a rate of about 0.3°C•h^{-1}. There were clearly no major differences between the clothing ensembles during **Rest**. The effect of subjects dropping out of the test before 150 min is clearly evident in these data as sharp steps or discontinuities in the curves. The biasing effect of subjects with a high cold tolerance is easily seen in the final 13 min of the data with the **CC** ensemble where only two subjects remained.

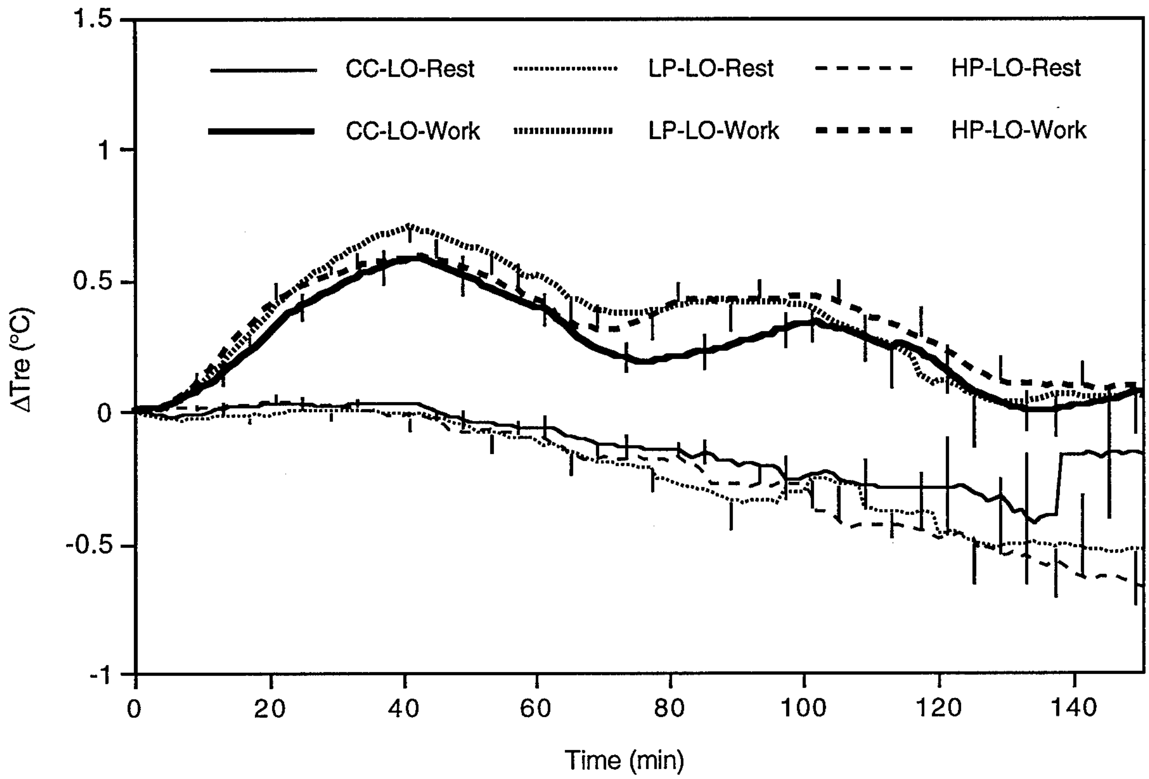

Figure 13. Mean change in rectal temperature (ΔT_{re}) vs time during the **Work** and **Rest** protocols under the **LO** wind condition at -40°C. The sharp discontinuities in some of the plots are due to subjects leaving the chamber at various times.

During the first work phase of protocol **Work** (0–40 min), T_{re} increased about 0.6–0.7°C but then fell sharply about 0.2°C during the rest phase. Upon completion of the rest phase and resumption of work at 60 min, T_{re} continued to fall at least another 0.2°C over the next 15 min before there was a turnaround in response. However, there was insufficient time remaining in the work phase to restore T_{re}, and cooling again took place during the second rest period. In contrast to the -10°C study, there did not appear to be a leveling off of deep body temperature, and it is not surprising that subjects could not endure the 150 min duration.

It is interesting to note in Figure 13 that, after the first 40 min and allowing for the cyclic undulations in the **Work** protocol data, the average rate of decrease of T_{re} was generally similar between the **Work** and **Rest** protocols. Given the large differences in physical activity (hence, metabolic rate) and clothing configurations between the two activity protocols (parkas on and off, open or closed, etc.), this similarity is best attributed to coincidence.

The ΔT_{re} data during the **HI** wind condition are shown in Figure 14. No subjects were able to tolerate 150 min with the **Rest** protocol unless wearing ensemble **HP**. While at first glance the differences in maximum tolerance times appear small (143, 136, and 150 min for ensembles **CC**, **LP**, and **HP**, respectively) and suggest this finding is trivial, a better appreciation of the benefits of the extra insulation in ensemble **HP** can be obtained by looking at the next-to-longest tolerance times for each ensemble. For example, two subjects completed 150 min with ensemble **HP**, and the third longest tolerance time was 115 min. Similarly, the longest tolerance time in ensemble **LP** was 136 min, followed by 110 min. In contrast, although one subject was able to tolerate 143 min with ensemble **CC**, the second longest tolerance time was only 82 min, and all data beyond that time are for a single subject. Thus, one can conclude from Figure 14 that the IECS is definitely superior to the current clothing during inactivity in high wind at -40°C.

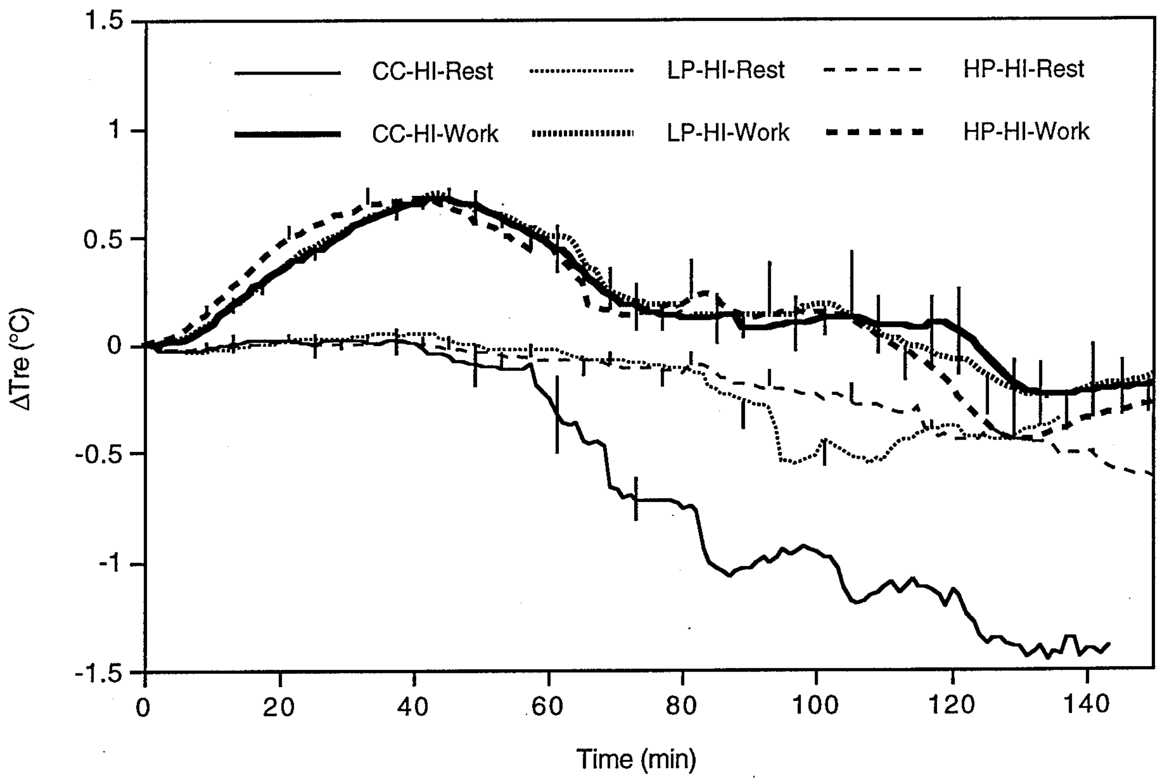

Figure 14. Mean change in rectal temperature (ΔT_{re}) vs time during the **Work** and **Rest** protocols under the **HI** wind condition at -40°C. The sharp discontinuities in some of the plots are due to subjects leaving the chamber at various times.

Mean Skin Temperature (MST)

Initial mean skin temperature (MST_i) differed significantly as a function of activity. However, the average difference was less than 0.5°C which was of no consequence to the subsequent evolution of skin temperatures during the exposures. The clothing by activity interaction was statistically significant and showed a progression of MST_i from 32.7°C to 33.2°C to 33.6°C for ensembles **CC**, **LP** and **HP**, respectively, during the **Rest** condition, but there were no differences during the **Work** condition. This is in keeping with the insulation levels of the clothing ensembles which were put on before entering the chamber during condition **Rest**; however, during condition **Work** the IECS parkas were carried into the chamber and MST_i showed no differences between clothing systems as a function of activity. Again, the range of 0.9°C between the average MST_i values was of no physiological consequence for subsequent skin temperature responses.

Statistical analyses of the final mean skin temperature (MST_f) data showed significant effects for all three main factors as well as for all levels of interaction. The plot for the 3-way clothing by wind by activity interaction is shown in Figure 15 and displays several interesting features. First, the **LP** and **HP** ensembles exhibited parallel changes between **Rest** and **Work** for each wind condition, but with slightly greater separation during the **HI** wind condition. This is entirely consistent with the fact that these clothing ensembles differed only in the quantity of insulation contained in the outer parka and trousers, and that there would be a greater cooling effect with increased wind. Second, the data for clothing ensemble **CC** also showed parallel changes in MST_f between **Rest** and **Work** for each wind condition, but in the opposite direction (i.e., an increase during **Work**). Considering that the body produces more heat during activity, the drop in MST with activity in the IECS may help to reduce sweating into the clothing. Of course, these opposite responses in MST are due to the fact that the IECS parkas were removed during the working periods of the **Work** protocol, thus implementing and demonstrating the effectiveness of the layering principle.

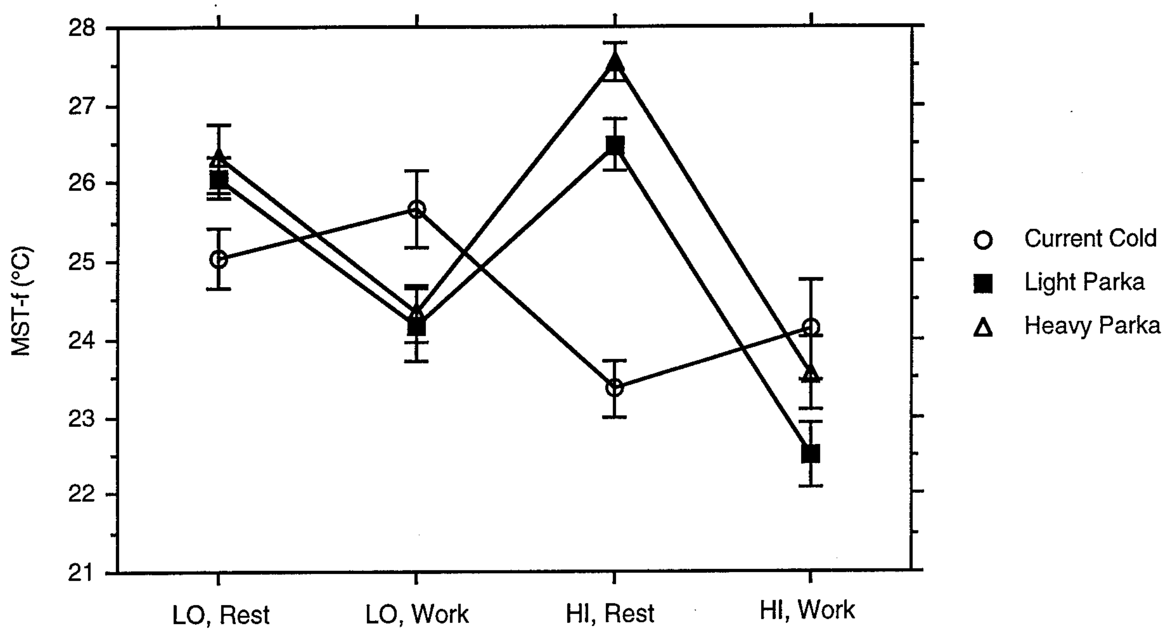

Figure 15. MST_f for clothing ensembles **CC**, **LP** and **HP** during activity protocols **Rest** and **Work** with **LO** and **HI** wind conditions.

Mean Heat Flux (MHF)

Because of the number of subjects dropping out over time in the -40°C tests, the plots of MHF over time were considerably "noisier" than those from the -10°C tests. However, the general trend was that whole body heat losses were less with the IECS compared to the current clothing during the **Rest** protocol, probably due to the superior insulation of the new clothing. During **Work**, heat losses were greater with the IECS because the parkas were removed for some of the time in the chamber. In general, the differences between **LP** and **HP** were less than the differences between the IECS and the current clothing. Thus, the MHF data support the idea that the IECS is an improvement over the in-service clothing.

Body Weight Changes (FLOSS)

Activity was the only factor to have a significant effect on FLOSS, but this finding is of little relevance to the objectives of this study. Overall average fluid losses were near 0.300 kg, probably because of the much reduced average durations of the -40°C exposures.

Heart Rate (HR)

As with the FLOSS data, activity was the only factor influencing HR to any great extent, a finding that does not discriminate at all between clothing systems.

Subjective Thermal Comfort

As at -10°C, thermal comfort ratings during the -40°C tests were obtained for the head, hands, feet and whole body. In addition, ratings were also obtained for the arms and legs since there were indications from the preliminary tests that these were body regions of possible discomfort. However, statistical analyses indicated very little in the way of significant effects involving clothing as a factor over the first hour of exposure (recall analyses were limited to 60 min due to subject dropout).

Significant interaction effects between clothing and activity were found for the head, whole body and arm comfort, with the following similar results in each case: subjects were generally warmer with the IECS ensembles compared with the **CC** clothing during **Rest**, but cooler during **Work**. This finding merely points out that removal of the outer layer of clothing to adjust insulation may have been a little too extreme for the particular conditions. However, with the IECS one still has the option of adding a parka, trousers, or both to gain insulation, and lesser amounts can be achieved by opening several of the zippers in the clothing. These procedures were not tried in this series of experiments, but there is no reason to believe they would not be practical and/or successful. By comparison, ensemble **CC** had far less versatility for maintaining comfort over a broad range of operational conditions.

Leg comfort depended heavily on clothing as a main effect ($p<0.001$) as well as on the clothing by wind interaction ($p<0.01$). The latter case is shown in Figure 16. It is quite clear that comfort ratings for the legs were not affected by wind when wearing the IECS, but they dropped considerably with ensemble **CC**. This could be attributed to the extra insulation of the IECS trousers that were worn during the **HI** wind **Rest** condition. Examination of the clothing by wind by activity interaction, although not statistically significant, confirmed that ensemble **CC** showed a large drop in leg comfort during **HI** wind **Rest** which was not seen with the IECS ensembles.

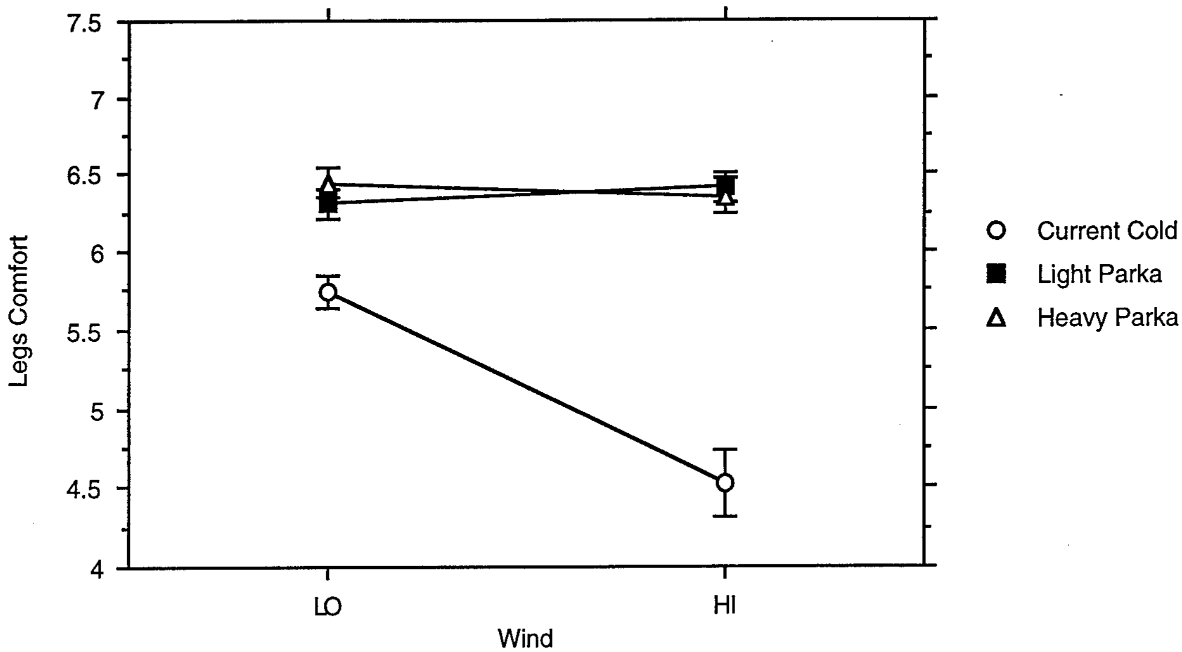

Figure 16. Clothing by wind interaction plot for leg comfort at -40°C.

It was interesting to note that hand and foot comfort data showed no statistically significant effects when clothing was a factor. This was likely due to the fact that the same items of clothing were covering the extremities in all tests. It could also be due to the fact that the data represent only values from the first 60 min of tests, and that longer exposures would have been required to show differences.

A specific objective of this portion of the study was to see if there were any statistically significant differences between the **LP** and **HP** configurations. This question was addressed by performing linear means comparison contrasts between the clothing ensembles. The contrasts were done at the clothing by wind by activity interaction level so that any differences as a function of wind and/or activity could be detected. While trends in the data were consistent with the differences in the levels of insulation, no statistically significant differences were found between these two ensembles.

CONCLUSIONS

The results of this study showed numerous instances in which the IECS demonstrated superior performance over the current in-service clothing systems. Some of these instances showed the IECS to be warmer than the current system, sometimes cooler, and sometimes it showed no change across test conditions. The point is that the IECS performed "better" than the other clothing configurations under most circumstances by preventing excessive cooling during periods of inactivity and overheating during work. It was certainly well liked by the subjects. The primary features of the clothing system that provide this improved performance are the wind-stopping water-vapour-permeable Goretex® membrane and the ease with which insulation levels can be adjusted to suit the situation.

As stated at the outset, it may not be materials themselves, but rather the clothing design and innovative approaches to incorporating new materials into these designs, that makes one ensemble superior to another. To illustrate, almost any amount of insulation can be provided in a garment system, but if the wearer is completely non-functional when fully dressed then the design is clearly poor and impractical. The flexibility, simplicity, good looks, good feel, and overall comfort of the IECS show that it is, in fact, very well designed. Perhaps the most important attribute of the IECS is that it finally makes the layering principle practical, and it does this with no sacrifice, and possibly even some significant gains, in thermal protection against the cold.

RECOMMENDATION

The IECS as tested in this study clearly demonstrated an overall superiority over the current in-service clothing. The advantages are primarily attributable to the successful implementation of the layering principle. Several minor operational deficiencies in the clothing were already known to exist before these tests were conducted, and changes to correct these deficiencies were already underway (replace some Velcro with buttons; change brass zippers to nylon; modify pockets, etc.). However, none of these changes would be expected to alter the physiological and subjective findings of this report. Any such minor changes that would enhance the operational functionality of the clothing without significantly affecting the thermal properties are endorsed. From a thermal physiological perspective, this clothing system is recommended for further development and implementation.

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APPENDICES

Appendix A: Procedural Details

Table A1: Thermistor Placement and Area Weighting Factors

Site Number	Site Location	Area Weighting Factor
1	Forehead	.070
2	Chest	.085
3	Calf	.065
4	Abdomen	.085
5	Forearm	.140
6	Hand (dorsal)	.050
7	Thigh (front)	.095
8	Shin	.065
9	Foot (dorsal)	.070
10	Upper back	.090
11	Lower back	.090
12	Thigh (rear)	.095

This is a standard surface area weighting system used at DCIEM. It is based on a modification of the widely-used Hardy and Dubois system (Hardy JD, Dubois EF. The technique of measuring radiation and convection. J. Nutr. 15: 461-475, 1938).

Table A2: McGinnis Thermal Comfort Scale

I am:

1. So cold I am helpless
2. Numb with cold
3. Very cold
4. Cold
5. Uncomfortably cool
6. Cool but fairly comfortable
7. Comfortable
8. Warm but fairly comfortable
9. Uncomfortably warm
10. Hot
11. Very hot
12. Almost as hot as I can stand
13. So hot I am sick and nauseated

Clothing Configurations

The following 5 tables list the actual clothing items worn during each of the various tests. Tables are of two basic types: current clothing or IECS. For each type of table, all clothing elements comprising the system are listed in the left column. However, only certain items would "normally" be worn under a given ambient temperature, and items not normally worn are shaded across the entire row. In those instances where it was felt that the normal clothing might lead to premature termination of a test because of severe discomfort or risk of cold injury, substitutions for some clothing elements were made; these are indicated in **boldface** type. There is only one table for the IECS clothing during the -40°C tests since the only difference between **LP** and **HP** was the level of insulation in the outer layer. Note that the white toque/balaclava was worn in both configurations as deemed necessary. In the last line of the tables, "a-c glove" refers to the cotton anti-contact glove which was sometimes worn inside the Arctic mitt.

Table A3: Current Temperate: -10°C

Temperature	-10°C			
Wind Speed	LO		HI	
Activity	Rest	Work/Rest	Rest	Work/Rest
Condition Code	CT-10-L-R	CT-10-L-W	CT-10-H-R	CT-10-H-W
personal undershorts	yes	yes	yes	yes
undershirt, cotton	yes	yes	yes	yes
underwear, honeycomb				
wool socks	yes	yes	yes	yes
shirt, combat	yes	yes	yes	yes
shirt, wool, cold weather				
trousers, combat	yes	yes	yes	yes
trousers, wind proof				
boots, combat	yes	yes	** no **	yes
mukluks			**yes**	
sweater	no	no	yes	no
scarf	no	no	yes	no
liner, combat coat	yes	no	yes	yes
combat coat	yes	yes	yes	yes
parka				
rain suit, hood up	no	no	yes	no
cap, wool, green	yes	yes	** no **	** no **
toque/balaclava, white			**balaclava**	**balaclava**
parka hood				
combat glove w. liner	yes	yes	** no **	** no **
a-c glove/Arctic mitt w. liner			**mitt**	**glove/mitt†**

† **glove/mitt** indicates the anti-contact glove was worn during the work phase and the mitt was worn during the rest phase.

Table A4: Current Cold: -10°C

Temperature	-10°C			
Wind Speed	LO		HI	
Activity	Rest	Work/Rest	Rest	Work/Rest
Condition Code	CC-10-L-R	CC-10-L-W	CC-10-H-R	CC-10-H-W
personal undershorts	yes	yes	yes	yes
undershirt, cotton				
underwear, honeycomb	yes	yes	yes	yes
wool socks	yes	yes	yes	yes
shirt, combat				
shirt, wool, cold weather	yes	yes	yes	yes
trousers, combat				
trousers, wind proof	yes	yes	yes	yes
boots, combat				
mukluks	yes	yes	yes	yes
sweater	no	no	yes	yes
scarf	no	no	yes	yes
liner, combat coat				
combat coat				
parka	closed	open/closed	closed	open/closed
rain suit, hood up				
cap, wool, green				
toque/balaclava, white	toque	toque	toque	balaclava
parka hood	down	down	up	down/up
combat glove w. liner				
a-c glove/Arctic mitt w. liner	mitt	glove/mitt†	mitt	glove/mitt†

† glove/mitt indicates the anti-contact glove was worn during the work phase and the mitt was worn during the rest phase.

Table A5: Current Cold: -40°C

Temperature	-40°C			
Wind Speed	LO		HI	
Activity	Rest	Work/Rest	Rest	Work/Rest
Condition Code	CC-40-L-R	CC-40-L-W	CC-40-H-R	CC-40-H-W
personal undershorts	yes	yes	yes	yes
undershirt, cotton				
underwear, honeycomb	yes	yes	yes	yes
wool socks, 2 pr	yes	yes	yes	yes
shirt, combat				
shirt, wool, cold weather	yes	yes	yes	yes
trousers, combat				
trousers, wind proof	yes	yes	yes	yes
boots, combat				
mukluks	yes	yes	yes	yes
sweater	yes	yes	yes	yes
scarf	yes	no	yes	yes
liner, combat coat				
combat coat				
parka	closed	open/closed	closed	open/closed
rain suit, hood up				
cap, wool, green				
toque/balaclava, white	balaclava	balaclava	balaclava	balaclava
parka hood	up	down/up	up	up
combat glove w. liner				
a-c glove/Arctic mitt w. liner	a-c in mitt	a-c in mitt	a-c in mitt	a-c in mitt

Table A6: New Temperate: -10°C

Temperature	-10°C			
Wind Speed	LO		HI	
Activity	Rest	Work/Rest	Rest	Work/Rest
Condition Code	NT-10-L-R	NT-10-L-W	NT-10-H-R	NT-10-H-W
personal undershorts	yes	yes	yes	yes
undershirt, cotton	yes	yes	yes	yes
wool socks	yes	yes	yes	yes
sweat shirt, fleece	no	no	no	no
sweat pants, fleece	no	no	no	no
shirt, combat	yes	yes	yes	yes
trousers, combat	yes	yes	yes	yes
trousers, uninsulated	yes	yes	yes	yes
boots, combat	yes	yes	** no **	yes
mukluks			**yes**	
jacket, uninsulated	yes	yes	yes	hood up
parka, insulated	yes	no	yes	at rest
overalls, insulated	no	no	no	no
cap, wool, green	yes	yes	yes	** no **
toque/balaclava, white				**balaclava**
parka hood	down	-- NA --	up	up at rest
combat glove w. liner	yes	yes	** no **	** no **
a-c glove/Arctic mitt w. liner			**mitt**	**glove/mitt†**

† **glove/mitt** indicates the anti-contact glove was worn during the work phase and the mitt was worn during the rest phase.

Table A7: Light/Heavy Parka: -40°C

Temperature	-40°C			
Wind Speed	LO		HI	
Activity	Rest	Work/Rest	Rest	Work/Rest
Condition Code	**-40-L-R	**-40-L-W	**-40-H-R	**-40-H-W
personal undershorts	yes	yes	yes	yes
undershirt, cotton	yes	yes	yes	yes
wool socks, 2 pr	yes	yes	yes	yes
sweat shirt, fleece	yes	yes	yes	yes
sweat pants, fleece	yes	yes	yes	yes
shirt, combat	no	no	no	no
trousers, combat	no	no	no	no
trousers, uninsulated	yes	yes	yes	yes
boots, combat				
mukluks	yes	yes	yes	yes
jacket, uninsulated	hood up	hood up	hood up	hood up
parka, insulated	yes	no	yes	at rest
overalls, insulated	no	no	yes	no
cap, wool, green				
toque/balaclava, white	balaclava	balaclava	balaclava	balaclava
parka hood	up	-- NA --	up	up at rest
combat glove w. liner				
a-c glove/Arctic mitt w. liner	a-c in mitt	a-c in mitt	a-c in mitt	a-c in mitt

Appendix B: Supplementary data

The following table lists some of the physical characteristics of the subjects used in this study. %BF was determined by standard underwater weighing techniques based on body density determinations.

Table B1. Subject Characteristics

Subject (No.)	Age (y)	Height (cm)	Weight (kg)	% Body Fat (%)
1	25	187	86.1	17.27
2	38	182	82.5	26.27
3	25	186	90.0	14.62
4	29	191	95.0	16.73
5	35	173	83.3	23.47
6	23	172	74	8.75
7	32	165	59.5	14.09
8	34	177	82.0	17.60
9	27	177	87.5	12.06
10	27	174	83.0	13.50
11	23	185	61.8	4.74
12	31	179	77.2	17.82
Mean	**29.1**	**179.0**	**80.2**	**15.6**
SD	**4.9**	**7.5**	**10.6**	**5.8**

The following table summarizes the relevant ANOVA results obtained in this study. Since the primary purpose of the study was to evaluate clothing, clothing is the only main factor shown. Furthermore, only those interactions in which clothing is involved are listed.

Table B2. Summary of ANOVA results.

		Factors			
Temp.	**Parameter**	Clothing	Clothing Wind	Clothing Act	Clothing Wind Activity
-10°C	Tre-i	NS	NS	NS	NS
	Tre-f	••	NS	••	NS
	ΔTre	•	NS	•	•
	MST-i	•	NS	NS	NS
	MST-f	•••	•••	••	NS
	ΔMST	•••	•	••	NS
	FLOSS	••	NS	••	NS
	Heart Rate	NS	NS	NS	••
	Head Comfort	•	•	•	•
	Hand Comfort	•••	•	•	NS
	Foot Comfort	•••	••	•	•••
	Body Comfort	•••	NS	••	NS
-40°C	Duration	NS	NS	NS	NS
	Tre-i	NS	NS	NS	NS
	Tre-f	NS	NS	NS	NS
	ΔTre	NS	NS	NS	NS
	MST-i	NS	NS	•••	•
	MST-f	••	•••	•••	•
	ΔMST	NS	••	•••	•
	FLOSS	NS	NS	NS	NS
	Heart Rate	NS	NS	NS	NS
	Head Comfort	NS	NS	•	NS
	Hand Comfort	NS	NS	NS	NS
	Foot Comfort	NS	NS	NS	NS
	Body Comfort	NS	NS	•	NS
	Arm Comfort	NS	NS	•	NS
	Leg Comfort	•••	••	NS	NS

Notes:
- • $p<0.05$
- •• $p<0.01$
- ••• $p<0.001$
- NS not significant

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PHYSIOLOGICAL EVALUATION OF THE IMPROVED ENVIRONMENTAL CLOTHING SYSTEM (IECS)
THE NEW CANADIAN FORCES COLD WEATHER CLOTHING SYSTEM (U)

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The Improved Environmental Clothing System (IECS) is a new cold weather clothing system designed to replace the current Canadian Forces in-service cold weather clothing system. The most unique feature of the system is that only the outer layer of clothing is added or removed as required to adjust the level of insulation during a change of activity level. The IECS uses Goretex® as a water-vapour-permeable wind and water barrier to partly achieve this unique functionality. The present study compared the physiological responses of human test subjects wearing the IECS or the current cold weather clothing system(s) in a laboratory setting under carefully controlled conditions of temperature (-10°C and -40°C), wind (0.4 and 20 km/h), and activity (rest or intermittent work). Measurements included physiological data (deep body temperature, skin temperatures, heart rate, sweat loss), body heat exchange, and subjective thermal comfort. The results showed numerous instances in which the IECS demonstrated superior performance over the current in-service clothing systems. It generally performed "better" than the other clothing configurations under most conditions by preventing excessive cooling during periods of inactivity and reducing overheating during work. The flexibility, simplicity, good looks, good feel, and overall comfort of the IECS show that it is well designed, and it was certainly well liked by the subjects. The most important attribute of the IECS is that it finally brings the layering principle into practicality, and it does this with no sacrifice, and possibly even some significant gains, in thermal protection against the cold.

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protective clothing, cold stress, comfort, Goretex, breathable fabric